



CHAPTER

10

ELECTROMAGNETIC INDUCTION

We have seen that an electric current can be produced using an electric battery. Can we have an electric current without any battery ? We are using electricity at our home. From where do we get the electric current in our home ? The electric current that we use in our home is generated at power plants also known as power stations. In this chapter we shall study the principle, working and uses of electric generator.

10.1 Electromagnetic induction

We have studied that a conductor carrying electric current perpendicular to the magnetic field experiences a force. This force causes the conductor to move. Can the reverse process be possible ? Can electric current be generated in the conductor when it moves perpendicular to the magnetic field ? This was first studied by English Physicist Michael Faraday. In 1831 he discovered that relative motion between a magnet and a coil can generate electric current in the coil. The phenomenon is known as electromagnetic induction.

To understand the discovery let us perform the following activity.

Activity 10.1

Take a coil of a large number of turns, a sensitive galvanometer and a strong magnet.

Connect the terminals of the coil to the galvanometer Figure 10.1. Push a pole, say N-pole of the magnet towards the end of the coil very quickly. Do you find any change in the galvanometer needle ? There is a momentary deflection

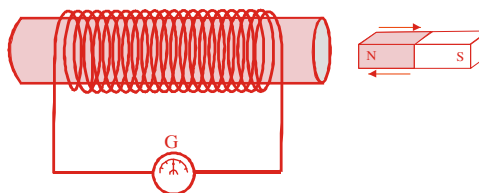


Figure 10.1

in the needle of the galvanometer. This indicates the presence of a current in the coil. The deflection becomes zero at the moment when the motion of the magnet stops.

Withdraw the N-pole of the magnet away from the coil very quickly. Do you find any deflection of the needle of the galvanometer? There is a momentary deflection of the needle in the direction opposite to the first.

Repeat the experiment using the other end of the magnet i.e. S-pole of the magnet. Record the finding.

Keeping the magnet stationary, move the coil towards and away from the magnet. Observe the deflection of the needle of the galvanometer. Observe the amount of deflection of the needle varying the speed of movement of the magnet or coil.

Whenever there is relative motion between the coil and the magnet electric current is developed in the coil. The phenomenon is known as electromagnetic induction. The current in the coil is called induced current and the potential difference developed between the ends of the coil is called induced voltage or induced e m f.

The result of Faraday's Experiment on electromagnetic induction may be summarised as follows :

- (i) Whenever there is a relative motion between a coil and a magnet an induced current flows in the coil. In other words, whenever there is a change in the number of magnetic lines of force linking with a coil an induced e m f is set up in the coil.
- (ii) Induced current in the coil lasts only as long as there is change in number of magnetic lines of force linking with the coil.
- (iii) The strength of induced e m f is directly proportional to the rate of change of magnetic lines of force linked with the coil.

In practice we can induce electric current in the coil either by rotating the coil in a magnetic field or by rotating a magnet (about a perpendicular axis) around the coil. It is convenient to rotate the coil in the magnetic field. The direction of the induced current depends upon the direction of the magnetic field and direction of motion of the coil. The induced current is found to be the highest when the direction of motion of the coil is at right angle to the magnetic field. In this situation, we can use a simple rule known as Fleming's right hand rule to know the direction of the induced current.

Fleming's right hand rule

Stretch the thumb, forefinger and middle finger of right hand so that they are perpendicular to each other as shown in the figure 10.2 . If the thumb shows the direction of motion of the conductor and the forefinger indicates the direction of the magnetic field, then the middle finger will show the direction of induced current in the conductor.

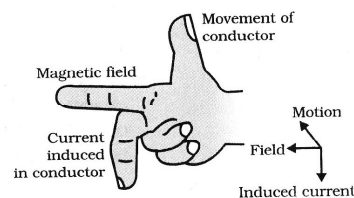


Figure 10.2

The principle of electromagnetic induction is used in the construction of generator, microphone, electric guitar, etc.

10.2 Electric Generator

Principle

Electric generator works on the principle of electromagnetic induction. In electric generator mechanical energy is used to rotate a coil in a magnetic field to produce electricity. Hence, generator is a device to convert mechanical energy into electrical energy. When the coil is rotated in the magnetic field the direction of the induced current changes alternately. A commutator may be used to produce the current in the same direction. Generators are of two types – A C Generator (alternating current Generator) and D C Generator (direct current Generator)

Construction

Figure 10.3 shows a schematic diagram of an A C Generator. An A C Generator consists of

- (i) Two pole pieces N-S of a permanent magnet.
- (ii) An armature consisting of a number of turns of rectangular coils. There is an arrangement to rotate the coil about an axle perpendicular to the magnetic field with a high speed. (It is represented in the diagram with a single turn coil ABCD)
- (iii) Two metal slip rings R_1 and R_2 connected to the two terminals of the coil.

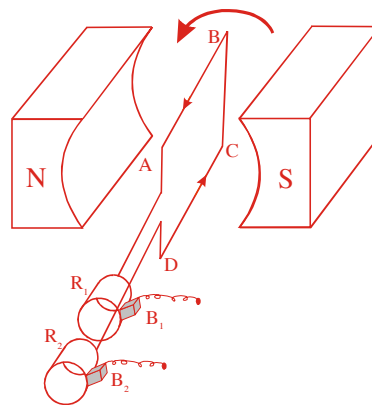


Figure 10.3

- (iv) Two stationary conducting brushes B_1 and B_2 , kept pressed separately on the rings R_1 and R_2 . The brushes are connected to two separate leading wires of an external load.

Working

At start let us assume that the plane of the coil is vertical with the side AB being uppermost and CD being lowermost. When the coil rotates the side AB moves downwards and CD moves upwards cutting across the magnetic field. Electric current is developed in the coil due to electromagnetic induction. Applying Fleming's right hand rule the direction of induced current will be along BA and DC. Now the current will complete its flow along DCBA then through R_1 to the external circuit or load and returning through R_2 .

After the completion of half rotation the side AB will occupy the lowermost and CD the uppermost position. When the armature continues its rotation the side AB moves upwards and CD moves downwards cutting across the magnetic field. In this second half of rotation the current will flow along AB and CD completing its circuit along ABCD then through R_2 to the external load and returning through R_1 . Thus the polarity of R_1 and R_2 changes alternately. After the completion of one rotation the armature will resume the starting position. Then the same cycle continues as the armature goes on rotating continuously. Thus the direction of current in the external circuit changes for every half rotation. Such current is known as alternating current (A C) and the generator is known as A C Generator.

If there are larger number of turns in the coil the current generated in each turn adds up to give a large current through the coil.

How frequently does the direction of the current change ? In a second the number of times the current flows in a given direction is known as frequency of the A C source. Frequency is the number of complete cycle in one second. Most of the A C generators are designed to have frequency 50 cycles per second (hertz- Hz). In such generators direction of current alters 100 times in a second.

D C Generator

To get a direct current (D C) which does not change the direction of current with time a split ring (a single ring splitted into two halves) is used as commutator. With this arrangement one brush is at all time in contact with the arm of the coil moving downwards in the field. While the other brush is in

contact with the arm moving upwards. Such generator which sends current in a direction only is known as D C generator.

Figure 10.4 shows the schematic diagram of a D C Generator.

Difference between AC Generator and DC Generator

- (i) In A C generator the direction of electric current reverses periodically. But in D C generator the current flows in one direction only.
- (ii) In A C generator there are two metal slip rings connected to the terminals of the coil separately. While in D C generator there are two split half rings (splitted into two halves from a single ring) connected to the terminals of the coil.

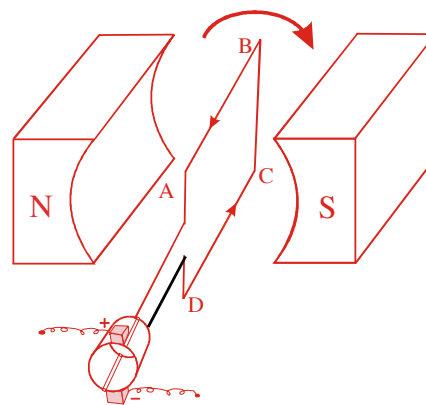


Figure 10.4

- (iii) In A C generator the two conducting brushes are in contact with the two rings separately. While in D C Generator the brushes are in contact with the two halves(split ring) alternately in the right time. A brush is always in contact with the half of the ring where electric current flows out and another brush is always in contact with the half ring where electric current returns. Thus a brush is always (+)ve terminal and the other is always (–)ve terminal.

The nature of variation of the generated e m f from an A C generator is shown in the figure 10.5. When the plane of the coil is perpendicular to the magnetic field any side of the coil does not move across the magnetic field. In the first quarter of its rotation the rate of cutting across the field

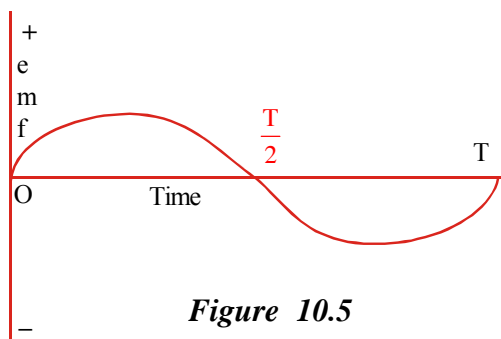


Figure 10.5

risks. Hence the e m f generated increases from zero to maximum value. During the second quarter e.m.f decreases and becomes zero. However, in the second half of the rotation the e m f generated follows the same pattern as obtain in the first half with the reversal in the direction of e m f only.

Advantage of AC over DC.

Voltage of A C can be stepped up or down easily with the help of a device called transformer. Energy loss in long distance transmission is large at low voltage and high current. It can be minimised by stepping up the voltage and reducing the current for long distance transmission. A C can be converted to D C more easily.

However, there are some devices where A C cannot be used directly.

10.3 Domestic electric circuits

We use different kinds of electrical appliances in our house. The electricity from a power station is transmitted through a long distance at high voltage. It is to minimise the loss of energy in the transmission line in the form of heat. The high voltage is reduced using a step down transformer at our locality. In our house we receive the electric power at 220 V. It is to suit with the domestic appliances commonly used.

The wiring inside the house is done according to our needs in different parts of the house.

The electric power lines enter our house through three wires consisting of live, neutral and earth. However, the live and the neutral wires are connected directly to the main supply through electricity meter.

The earth wire is connected to a large metal plate which is embedded deep in the earth in a moist region near the house. The earth wire carries no electricity. The neutral wire is maintained at the zero potential by connecting it to the earth at the power station. This provides the return path for the current. The live wire is at a high potential.

There is a colour convention for wiring. According to this convention

- live line has red insulation
- neutral has black insulation and
- earth has green insulation.

(in some countries black is used for live, white for neutral and green for earth).

In a house we use a number of appliances like electric bulbs marked 220V – 60W, 220 V – 100W, 220V – 200W, 220V–1000W, heater marked 220V – 1000W, electric iron marked 220V – 500W, electric fan marked 220V – 60W, etc. From this we must know that each of them requires 220V potential difference for proper functioning.

If a number of appliances are connected in series to the power supply the appliances cannot get the right potential difference and hence they cannot function properly. Another disadvantage of series connection is when the resistance of an appliance gets fused or switched off the other appliances will not get the electric current and hence will not work. If the appliances are connected in parallel each appliance can get the proper voltage to function properly and separate switches can be put for each appliance. Another advantage of parallel connection is that even when one part is switched off or fused the other parts are not affected.

However, when connected in parallel each part will draw different current according to their rating. When they are used simultaneously the total current drawn from the main will be the sum total of the currents in each appliance. Hence, it may be very large.

Again a bulb marked 220V – 100W has a resistance of 484 ohms and will draw a current of about 0.45A. A heater of 220V – 2000W has a resistance of 24.2 ohms and will draw a current of about 9A. To carry a larger current we need thicker wires and better quality materials in switches and sockets.

The appliances used at our house may be categorised into two groups – (i) light power appliance – like electric bulb, fan, TV sets, radio, etc. which draw current less than 5 A and (ii) high power appliance – like heater, cooker, refrigerator, etc. which draws larger current above 5 A when a few of them are used simultaneously. So, it is convenient to provide two different main lines – 5A line and 15A power line through different boards for 5A and 15A sockets and switches. (They are available in the market with specification).

Some electrical appliances like bulbs, tubes, fans, need not be connected with earth. They have just two terminals to be connected to the live and neutral. A wire from the live line passes through a switch then to one terminal of the appliance. The neutral line is connected to the other terminal of the appliance. The switch is placed at a convenient height to enable us to operate it.

Some appliances have plugs instead of the permanently fixed terminals. An electric iron is an example. It has a plug at the end of the cord. The plug (may) contain three pins. The pins correspond to Earth, Neutral and Live generally marked with letters E, N and L near the pins. For them we need socket. The socket is fitted permanently on a switch board and the three lines Earth, Neutral and Live are connected to the terminals at the back of the socket. Usually the live wire is passed through a switch before it is connected to the socket.

Role of fuse – a safety device

The wire used for wiring have limit for a certain maximum current to pass through them. If the current exceeds that limit, the wires may get over heated and cause fire. There are two main reasons for increasing current in the wires. They are – (i) Overloading (electrical power consumed by the appliance is greater than the maximum wattage) and (ii) short circuiting (direct connection of the live and neutral wires). Whenever there is short circuiting wires may be overloaded and at the same time at the point of short circuit sparking may occur and cause a fire.

Many precautions and safety measures are taken up to protect from the possible damages. All wires used in domestic electric circuits are coated with a layer of insulating material like rubber or plastic. So, the wires do not come in direct contact and short circuit does not occur. Besides there is division of circuits into different sections. This process not only facilitates repair of each section independently but also restricts the damage due to over loading or short circuiting.

The most important safety device used for protection of electrical circuits is the use of fuse. The fuse is a piece of wire made of material with a low melting point. Whenever a high current flows in the circuit due to overloading or short circuiting, the fuse gets heated then melts and disconnects the circuit from the main supply line. Fuse must be connected to the live wire.

Fuse wire is made of pure tin, but a cheaper variety is made of an alloy of tin and copper. The thickness and length of fuse wire depend on the maximum current permitted through the circuit.

Two types of electric fuse and circuit symbol of a fuse are shown in the figure 10.6.

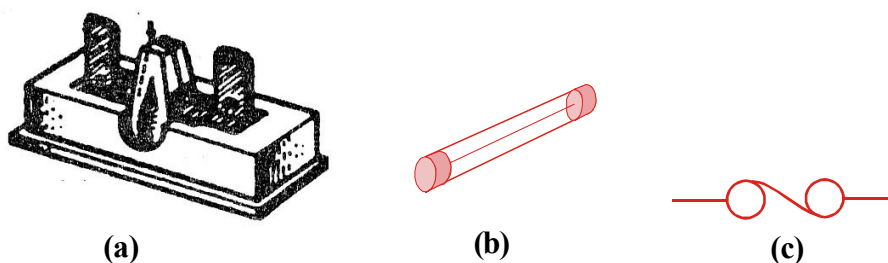


Figure 10.6

Figure 10.7 shows a schematic diagram of a common domestic wiring.

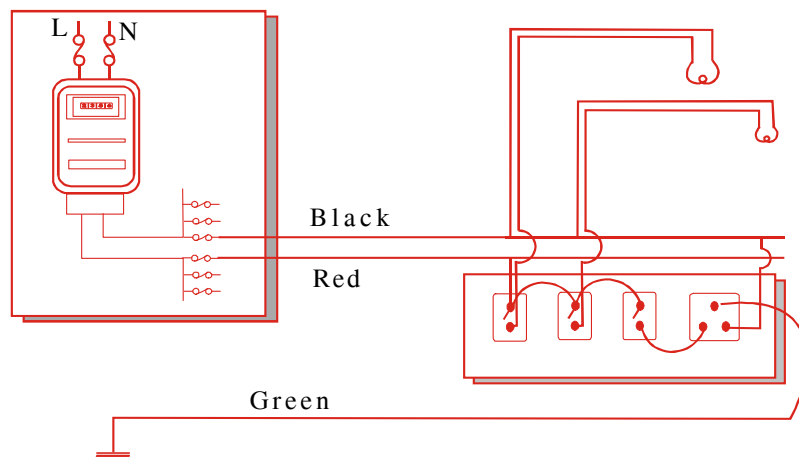


Figure 10.7

10.4 Hazards of electricity and precaution

Electricity is one of the most important and convenient sources of energy available to us. It can be used for different purposes. However, it is dangerous if certain precautions and safety measures are not taken up while use. You know that if you touch any point of the electric circuit you get shock (but don't try it). Sometimes the shocks are too severe to kill the person. The cracks or flaws in electric circuits (loose connection) defective switches, damaged wire, short circuit or overloading may cause sparking or overheating that may cause fire in the house. To avoid such hazards we require not only the safety devices of using fuse but also the following precautions in handling electric circuits.

- (i) The metallic body of certain appliances like wattmeter, main switch, refrigerator, electric iron, computer, etc. must be connected to the earth wires. The reason for this is, if there is a slight leakage of current to the body of the appliance its potential remains the same as that of the earth and prevents from electric shocks.
- (ii) All household wires must be of good quality and properly insulated (insulation thickness must be proper). Any exposed part must be insulated.
- (iii) No direct handling must be done while repairing any part of a circuit. Use rubber hand gloves and wear rubber shoes or put off the main switch at the entry of main supply.

- (iv) The tools like tester, pliers, screw drivers, pincers used in repairing should have proper insulation.
- (v) One should not touch the metallic body of any electric appliance when they are switched on, if proper earthing is not given to them.
- (vi) One should not touch any part of electric appliances and even the switches with wet skin and bare footed.
- (vii) In case of fire, the main switch must be immediately switched off.
- (viii) Electric fuse should be used in each section. Proper fuse should be used. The practice of using ordinary copper wires instead of proper fuse wires can cause accident.

Despite of all precautions, it is possible that someone accidentally touches a live wire of the overhead domestic supply or inside the house. If this happen one should try to provide such a person with a support of some non-conducting materials like dry wood, plastic, rubber etc. One should try to pull away the person, who has contacted the live wire by not touching directly. The first and most appropriate step is to switch off the current at once.

Remember electricity is your friend so long as you take proper care. It can be fatal if you fail to observe the guidelines for using electricity.

10.5 Electric Power plants

From where do you get electricity at your home ? The electricity that we use is generated at power plants or station. In the power stations the armature of the generator is rotated by connecting its shafts to a prime mover. Power plants can be named according to the method used to rotate the armature. Some important ones are described below :

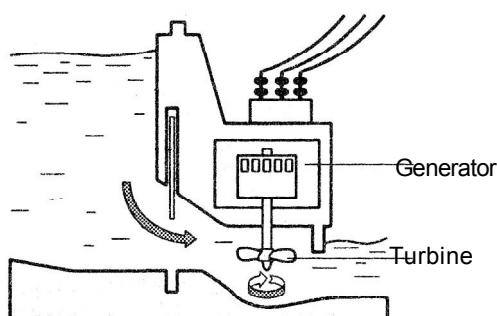


Figure 10.8 Hydel power plant

(a) Hydel (hydro electric) Power plants

In this type of power plant water at the higher level is allowed to fall on the blades of the turbine Figure 10.8. The pressure of water makes the blades of the turbine move making the armature (coil) of the generator rotate with a great speed. Then electricity is produced. Indira Gandhi Loktak Hydro electric project at Leimatak and Nungsangkhong Hydel power station at Ukhrul are examples of Hydel power plants.

(b) Thermal Power plant

In this type of power plant water is boiled using coal as fuel. Steam is produced at high pressure in the boiler. The steam is used to drive the turbine Figure 10.9. Then the armature coil of the generator is rotated. Thus electricity is produced.

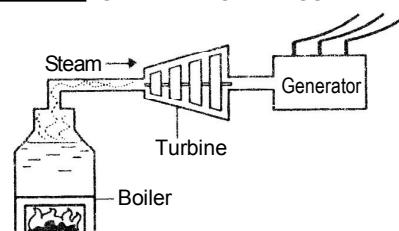


Figure 10.9 Thermal power plant

(c) Nuclear Power plant

In nuclear power plant also known as Atomic Power plants the energy released through fission is used to produce steam by boiling water. The steam in turn, is used to rotate the turbine of electric generator Figure 10.10.

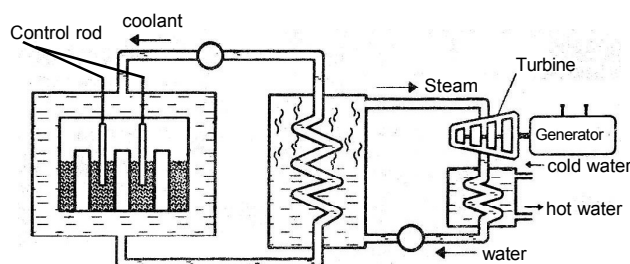


Figure 10.10 Nuclear power

(d) Genset

Genset also known as Generator set is a small unit. In a Genset diesel, petrol or kerosene engine is used to rotate the armature coil of the generator. A genset can be small enough to meet the requirement of a single house or large enough to be used in a small industrial unit.

POINTS TO REMEMBER

- i. When there is a change in the number of magnetic lines of force linked with a coil an induced e m f is developed in the coil. The phenomenon is known as electromagnetic induction.
- ii. The strength of the induced e m f is proportional to the rate of change of the number of magnetic lines of force linked with the coil.
- iii. The direction of the induced current in the coil is given by Fleming's right hand rule.
- iv. Electric generators work on the Principle of electromagnetic induction.
- v. A generator converts mechanical energy into electrical energy.
- vi. An A C has some advantages over D C.
- vii. In domestic wiring earthing and use of proper fuse are very important.
- viii. Power plants can be named according to the method used to rotate the armature.

EXERCISE

1. A coil of copper wire is connected to a galvanometer. What would happen if a bar magnet is (a) pushed into the coil very slowly ? (b) pushed into the coil very rapidly? (c) held at rest inside the coil ? (d) pulled out again rapidly ?
2. State the principle of the electric generator.
3. Explain with diagram the action of either A C generator or D C generator.
4. Distinguish between A C and D C.
5. What is the purpose of Fleming's right hand rule ?
6. A dynamo converts energy from one form to another. Name the two forms of energy in proper sequence.
7. A galvanometer is connected to the ends of a metal rod. The rod falls with its length horizontally extending East-West. What changes will you observe in the galvanometer? Explain the reason.
8. A galvanometer is connected to the ends of a metal rod. The rod falls with its length horizontally extending North-South. What changes will you observe in the galvanometer ?
9. Name two devices in which the principle of electromagnetic induction is used.
10. Many electrical appliances and circuits are earthed. What is the reason?
11. What is the usual colour code followed for connecting live, neutral and earth wire ?
12. What is meant by overloading in an electric supply ? How can it be prevented ?
13. What precautions should be taken to avoid overloading of domestic electric circuit ?
14. Why is material of low melting point chosen for fuse wire ?
15. What is short circuiting ? Mention the possible consequences of short circuiting.
16. Explain two safety measures commonly used in electric circuit and appliance.
17. What are the advantages of parallel connection of the domestic appliances in house hold wiring ?

18. For domestic wiring give reasons why sections are separated.
19. In a switchboard there are three switches with no socket or any other element. How many wires will be going in the switch board ?
20. Is it possible to step up D C using a transformer ?
21. What is the use of a commutator in generator ?
22. Mention an important advantage of A C over D C.
23. Name three main types of power plants.
24. Which device is used to change the A C voltage ?
25. In a thermal power plant, how is the turbine rotated ?
26. How is the turbine rotated in a Hydel power plant.
27. What is the basic difference between thermal power plant and hydel power plant ?
28. How is the core of the coil of a Genset rotated to produce electricity ?

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